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Abstract

Purpose: The purpose of this paper is to evaluate the limitations and emerging trends of Six Sigma through an empirical study. Six Sigma is one of the most powerful business process improvement strategies used by numerous World Class corporations for over three decades. A handful of existing publications address some limitations and potential trends of Six Sigma, yet there are no empirical studies investigating the fundamental limitations and emerging trends of Six Sigma.

Methodology: The authors developed an online survey instrument based on the existing literature addressing the above. In this study, 61 Six Sigma Master Black Belts and Black Belts from large manufacturing companies and 25 academics who are familiar with the Six Sigma topic participated and contributed to the research.

Findings: The study reports the top five limitations and emerging trends of Six Sigma from the viewpoints of both academics and experts from large manufacturing companies. These are: *integration of Six Sigma with Big Data, Use of Six Sigma in Small Medium and Micro enterprises, over emphasis of Six Sigma on variability reduction, poor implementation of Six Sigma and its negative impact on employee satisfaction and non-exploitation of integration of Six Sigma with Industry 4.0.*

Practical Implications: In order to sustain Six Sigma initiatives, it is imperative that limitations and fundamental gaps are understood, and strategies developed to address them. The authors argue that leading academic scholars have a vital role to play in working with industry practitioners to overcome the limitations and emerging trends addressed above.

Originality of Value: To the best of our knowledge, this is the first empirical study looking into the limitations, research gaps and emerging trends of Six Sigma.

Keywords: Six Sigma, Limitations, Empirical Study, Survey, Research Gaps, Emerging Trends

1.0 Introduction

Six Sigma is one of the most widely used business process improvement strategies, adopted by many World Class organisations over the last three decades (Antony et al., 2017). Bill Smith, an engineer within Motorola, developed Six Sigma in the Motorola Corporation in the mid-1980s. Since the 1990s, many companies such as Allied Signal (known today as HoneyWell), General Electric, Caterpillar, Cummins, ABB, Johnson and Johnson, American Express, and Bank of America have used Six Sigma, resulting in millions of dollars of bottom line savings (Snee, 2004, 2010; Antony et al., 2017).

Six Sigma is a business process improvement methodology, which aims to identify and eliminate causes of defects or mistakes or errors in business processes. The focus of Six Sigma is on critical processes that result in unacceptable defects in the eyes of customers. Six Sigma principles can be used to improve the process average and design, create robust products, services and processes, and reduce excessive variation in the process (Shah et al., 2008). Six Sigma methodology is statistically driven and this data driven approach to problem-solving often results in dramatic bottom line results (Snee and Hoerl, 2007). Schroeder et al (2008, p. 540) defined Six Sigma as "*an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives*". This definition of Six Sigma contains both the "what" and "how" of the theory, making it one of the most comprehensive definitions of Six Sigma to date.

Previous studies have reported some of the limitations of Six Sigma (Antony, 2004a; Mitra, 2004; Goodman and Theuerkauf, 2005; Bisgaard and De Mast, 2006; Angel and Pritchard, 2008; Chakravorty, 2009a, 2010). This study extracts the limitations of Six Sigma from current literature and investigates them using an online survey protocol with a number of subject matter experts: Six Sigma Master Black Belts and Black Belts in large manufacturing companies. A number of leading research scholars and academics, who are involved in teaching and research on Six Sigma topics in their respective universities, also participate in our study. The remainder of the paper is organized as follows: the next section presents the limitations and research gaps of Six Sigma in the literature, followed by the research methodology used in the study. The key findings are then analysed and discussed , along with the implications, limitations and finally the scope for future research.

2.0 Literature Review: Limitations, Trends, and Gaps in Six Sigma Research

Towards a deeper understanding of the Six Sigma, a literature review was undertaken to find publications reporting the limitations, emerging trends and research gaps of Six Sigma. This review identified 15 limitations/research gaps/emerging trends from various sources (Sony et al., 2018). .

2.1 Limitations of Six Sigma

It was observed that the failure rate of Six Sigma is very high, in keeping with other organizational change initiatives. This first limitation is viewed as a major research gap for companies keen to invest in Six Sigma initiatives. For instance, (Glasgow et al. (2010) and Albliwi et al. (2014) report that over 60% of Six Sigma initiatives failed to deliver the desired results. Like any other quality improvement initiative, Six Sigma starts off well; but fails to have a lasting impact over time. As a result, motivation and momentum drop, and organizations fall back into old habits (Chakravorty, 2005). Several studies show that around 60% of all corporate Six Sigma initiatives fail (Angel and Pritchard, 2008; Chakravorty, 2009a, 2009b, 2010). It is estimated that almost 70% of change management initiatives in organizations fail (Beer and Nohria, 2000; Hughes, 2011), similar to Six Sigma at around 60-70% (Spector and Beer, 1994; Hughes, 2011; Pedersen and Huniche, 2011; Bhasin, 2012). Due to these failures, more corporations across multiple industry sectors are pulling back on their Six Sigma initiatives. It is felt that the methodology alone is not a cure-all for corporate ills (Angel and Pritchard, 2008; Chakravorty, 2009b). This presents a clear gap in understanding around the reasons for failures and a need to develop remedial strategies to mitigate future failures.

The second limitation is that the initial cost of implementing Six Sigma in an organization is very high (Berg, 2006). The initial cost for institutionalising Six Sigma in corporate culture can be a substantial investment (Fursule et al., 2012). This discourages many small and medium-size enterprises (SMEs) from the introduction, development, and implementation of Six Sigma strategies (Antony, 2006; Abdolshah et al., 2009; Homrossukon and Anurathapunt, 2011; Vendrame Takao et al., 2017).

The third limitation is that Six Sigma may have a negative impact on customer satisfaction if not implemented properly (like any other business improvement initiative) (Hindo, 2007a; Hindo and Grow, 2007; Angel and Pritchard, 2008). Two major global US corporations (3M and Home Depot) abandoned their Six Sigma program due to a negative impact on customer satisfaction (Hindo, 2007a; Hindo and Grow, 2007; Chakravorty, 2009a). At the same time, several studies suggest that proper implementation of Six Sigma promotes customer satisfaction and innovation (Fortenot et al., 1994; Behara et al., 1995; Montgomery, 2008; Antony et al., 2016; He et al., 2017).

The fourth limitation of Six Sigma is that poor implementation of Six Sigma can have a negative impact on employee satisfaction. Differing levels of implementation of Six Sigma result in differing levels of job satisfaction amongst employees (Alexander, 2001). Poor implementation of Six Sigma will have a negative impact on employee morale and engagement (Schön et al., 2010).

The fifth limitation of Six Sigma is that this structured and disciplined approach to problem solving may stifle employee creativity and innovation (Hindo, 2007a; Hindo and Grow, 2007). The line of thinking is that Six Sigma's sequence of steps and rigorous, analytical method leads people towards rigidity (Hindo, 2007b; Angel and Pritchard, 2008). There are two schools of thought around this limitation; one claiming that Six Sigma stifles employee innovation skills (Hindo, 2007a; Hindo and Grow, 2007; Angel and Pritchard, 2008) and the other claiming that Six Sigma fosters innovation ((Montgomery, 2008; Hoerl and Gardner, 2010).

The sixth limitation of Six Sigma is that the benefits of Six Sigma implementation do not outweigh the effort and costs of implementation (Foster Jr, 2007). Being a statistical and data-driven methodology, the effort required to implement Six Sigma can be very high in terms of the resources and time spent in completing complex projects thus, relative to these efforts, the benefits of Six Sigma programs are minimal (Foster Jr, 2007; Gupta, 2008; Chakravorty, 2009a). At the same time, a number of studies report successful Six Sigma implementation resulting in huge financial savings (Kwak and Anbari, 2006; Asefeso, 2014; Pyzdek and Keller, 2014). This suggests empirical studies are needed to understand the relationship between investment made on Six Sigma by corporations and the benefits (hard and soft savings) accrued over time.

The seventh limitation surrounds technical criticisms of Six Sigma, such as the 1.5σ shift in process mean assumption for long-term variability study in business processes. The argument about the assumption of the process mean to be shifted by 1.5σ is groundless (Ramberg, 2000). If the Six Sigma process mean were centred on the target value with no σ shift, then the process would have produced defectives at a rate of two parts per billion (Antony, 2004a; Shahabuddin, 2008). When the process mean shifts by 1.5 σ, the defect rate will increase from 2 parts per billion to 3.4 ppm defects per million opportunities (Raval and Muralidharan, 2016). This assumption cannot hold true for all business processes in organisations, such as banking, billing, invoicing, recruitment and hiring process (Antony, 2006; Natarajan and Morse, 2009; Muralidharan, 2015a).

The eighth limitation is an overemphasis on variance reduction in processes. Although Six Sigma is a powerful philosophy, strategy, and methodology for understanding, quantifying and reducing variation in all business processes (Pande et al., 2000; Natarajan and Morse, 2009), in some cases it is essential to understand the trade-off between the degree of variability reduction and the benefits gained in real-life situations. Many companies around the world have built entire cultures upon this foundational concept (Ranjan Senapati, 2004), yet variation reduction is only one aspect of organisational inefficiency to be considered, and should not always take priority.

The ninth limitation is a question of originality: what is new in Six Sigma? Many view Six Sigma as TQM with a new label, or 'old wine in a new bottle', yet there are critical and fundamental differences between Six Sigma and other quality improvement initiatives such as TQM (Antony, 2009). The literature shows that in order to successfully implement Six Sigma, an expert requires:

- an in-depth knowledge of the tools and techniques of Six Sigma;
- a working understanding of inferential and descriptive statistics;
- the capability to convince and manage people (Gijo and Rao, 2005; Bisgaard and De Mast, 2006);
- project management skills (Antony and Banuelas, 2002);
- the ability to select, prioritize, and align projects with business strategy (Kumar et al., 2009);

- visionary leadership and uncompromising commitment from the senior management team (Byrne, 2003; Antony, 2011; Jesus et al., 2016);
- efficient and effective organisational infrastructure (i.e. the Belt system) (Schroeder et al., 2008).

The tenth limitation of Six Sigma is a criticism around the non-standardisation of the curriculum. Training, followed by the execution of a process improvement project based on the application of Six Sigma methodology (Define-Measure-Analyse-Measure-Control or DMAIC), is the key to the successful implementation of Six Sigma within an organisation (Coronado and Antony, 2002), yet non-standardisation of the Six Sigma curriculum for Yellow Belts, Green Belts and Black Belts has been a constant problem. The competencies and skills developed at the various belt levels vary significantly across organisations, necessitating further research towards effective standardisation (Laureani and Antony, 2011). A non-standardised education system creates a variety of learning patterns, which may be detrimental not only to the implementation of Six Sigma but also to its further growth.

2.2 Emerging trends and gaps in Six Sigma research

An emerging trend in Six Sigma research stems from the Big Data revolution. Big Data must be approached carefully towards a meaningful analysis through Six Sigma (Antony et al., 2017). This presents the first research gap, requiring equal attention from leading academics and industry practitioners. Few studies explore the relationship between Six Sigma and Big Data directly, through either theoretical or empirical research. Stojanovic et al. (2016, p. 1647) propose "a novel approach for data-driven Quality Management in industry processes that enables a multidimensional analysis of the anomalies that can appear and their real-time detection in the running system". Similarly, a recent study highlights the usage of Big Data-driven clustering for an efficient discovery of real-time defects in the process and their root-cause analysis (Stojanovic et al., 2015).

The second emerging trend and gap in Six Sigma research is the neglect of environmental aspects in Six Sigma deployment. Most companies do not take green concepts into account while implementing Six Sigma (Muralidharan, 2015b). The commonly used tools and measures to address a firm's environmental impacts have evolved from the 3R approach of a circular economy (*reduce, recycle, reuse*) towards cost reductions and potentially reducing

taxes and liability insurance. This emphasizes the need for a fundamentally new model of industrial organization to reconcile rising demands for quality products and services with prosperity, and eco-friendly products and services with resource depletion – a model that goes beyond incremental efficiency gains to deliver transformative continuous improvement (Bocken et al., 2016).

The third trend of Six Sigma emerges in the wake of the Industry 4.0 revolution, the integration of Six Sigma into which presents a significant challenge (Basios and Loucopoulos, 2017). Future processes will become smarter by embedding various technologies from Industry 4.0 and incorporating the ensuing flood of data (Sony, 2018) into Six Sigma business process improvement strategy. The predictive and self –learning measures of modern machines, smart materials, and objects will require new analytical tools, which may be used in tandem with existing Six Sigma tools. Future research may explore these areas.

The fourth emerging trend of Six Sigma is its suitability in the context of SMEs particularly small and even micro enterprises with less than 10 people working in a company (Deshmukh and Chavan, 2012). SMEs have their own set of issues and challenges that may not be generalizable throughout the business community. As such, the identification of an SME-specific it would be of great benefit if a set of continuous improvement tools and techniques would be of great benefit (Alexander et al., 2018). Without a proper, balanced and effective infrastructure, Six Sigma projects cannot be effectively executed by SMEs and micro-enterprises. This is an unexplored area of research which requires further attention from both academic scholars and industry, through attention to research questions such as: How many Green Belts and Yellow Belts are required for successful deployment of LSS in an SME environment? What is the scope of Six Sigma projects in an SME environment? What is the nature of Six Sigma curriculum most suited to SMEs? (Alexander et al., 2018).

The fifth emerging trend of Six Sigma regards its applications in public sector organisations. An important related question concerns how public sector organisations might work together to maximize benefits, reduce duplication, and deliver a customer-focused and integrated service. The impact of Six Sigma on local councils, higher education, emergency services,

municipalities etc. should be further researched for its long-term suitability (Antony et al., 2016; Antony et al., 2017).

3.0 Research Methodology

The research questions driving this study are:

a) *What are the top five limitations/emerging trends/research gaps of Six Sigma from the view of Six Sigma experts such as Master Black Belts, Black Belts and Green Belts in Manufacturing sector?*

b) What are the top five limitations/emerging trends/research gaps of Six Sigma from the leading academic's perspective?

c) Is there a difference in the perception of limitation/emerging trends/research gaps between the above two clusters?

In order to address these research questions, the authors conducted a cross sectional study of Six Sigma experts at a global level using an online survey protocol.

3.1 Development of Survey Instrument

Data was collected through an online survey directed to large manufacturing companies, as well as academics and research scholars who have published peer reviewed articles on Six Sigma. The online survey was chosen due to its low cost and the ability to send the questionnaire in a standardized way, using self-administered methods by the respondents (Couper and Miller, 2008). The online survey was designed in Google Forms due to speed and simplicity of composition, with responses collected in an online spreadsheet. The target respondents were identified using the Linkedin contacts of authors; deemed a sensible approach due to the global nature of the survey.

An invitation to participate in the survey was sent to respondents who are Six Sigma Master Black Belts, Black Belts, Green Belts, academics and research scholars. The purpose of the research, its importance and benefits of participation were explicitly stated in the invitation message. The questionnaire has two parts; the first part gathering general information about the individual completing the questionnaire along with background of the participant's

company and the second part consisting of all fifteen limitations/emerging trends/research gaps of Six Sigma, rated on a Likert scale of 1 to 7 (1 = strongly disagree and 7 = strongly agree).

The online survey questionnaire was initially piloted with ten people (Boynton, 2004). This included three Six Sigma Master Black Belts, two Six Sigma Black Belts and five leading academics (those publishing peer reviewed articles on the topic of Six Sigma for at least ten years). The purpose of piloting the survey questionnaire was to ensure that the contents are valid and the questions are in alignment with the research objectives set by the researcher (Couper and Miller, 2008). The respondents for the pilot survey were asked to provide feedback on simplicity, relevance, and clarity, and the time taken to complete the questionnaire was noted. Feedback from all respondents was positive and some minor amendments were made on the questionnaire prior to contacting experts and academics.

3.2 Data Collection

The revised online survey link was sent out to 300 subject matter experts (Six Sigma Master Black Belts, Six Sigma Black Belts and Six Sigma Green Belts) and 50 academics who have been researching and publishing peer reviewed articles on Six Sigma topics for the past 10 years. A total of 86 responses were collated over an eight week period, which yielded a response rate of 24.5%. Easterby-Smith et al.(2012) argue that a 20% response rate in surveys is widely considered sufficient, while the literature on Lean and Six Sigma suggests that even a 10% response rate is acceptable (e.g., Shah et al. 2008). This view is supported by Collis and Hussey (2013) who argued that researchers using survey questionnaire techniques should expect a minimum response rate of 10%. Table 1 and Figure 1 respectively show the distribution of the respondent characteristics and country-wise distribution of respondents. The country-wise distribution of experts in the manufacturing sector is illustrated in Figure 2. The majority of respondents come from the Mining, Automotive, Heavy electricals, Petroleum and Chemicals industries.

Table 1: Respondent Characteristics on expertise in Six Sigma

		Which of the following sector you work for?		
		Academic	Manufacturing	Total
Six Sigma Belt	Black Belt	3	20	23
	Master Black Belt	10	35	45
	Green Belt	4	6	10
	None	8	0	8
Total		25	61	86

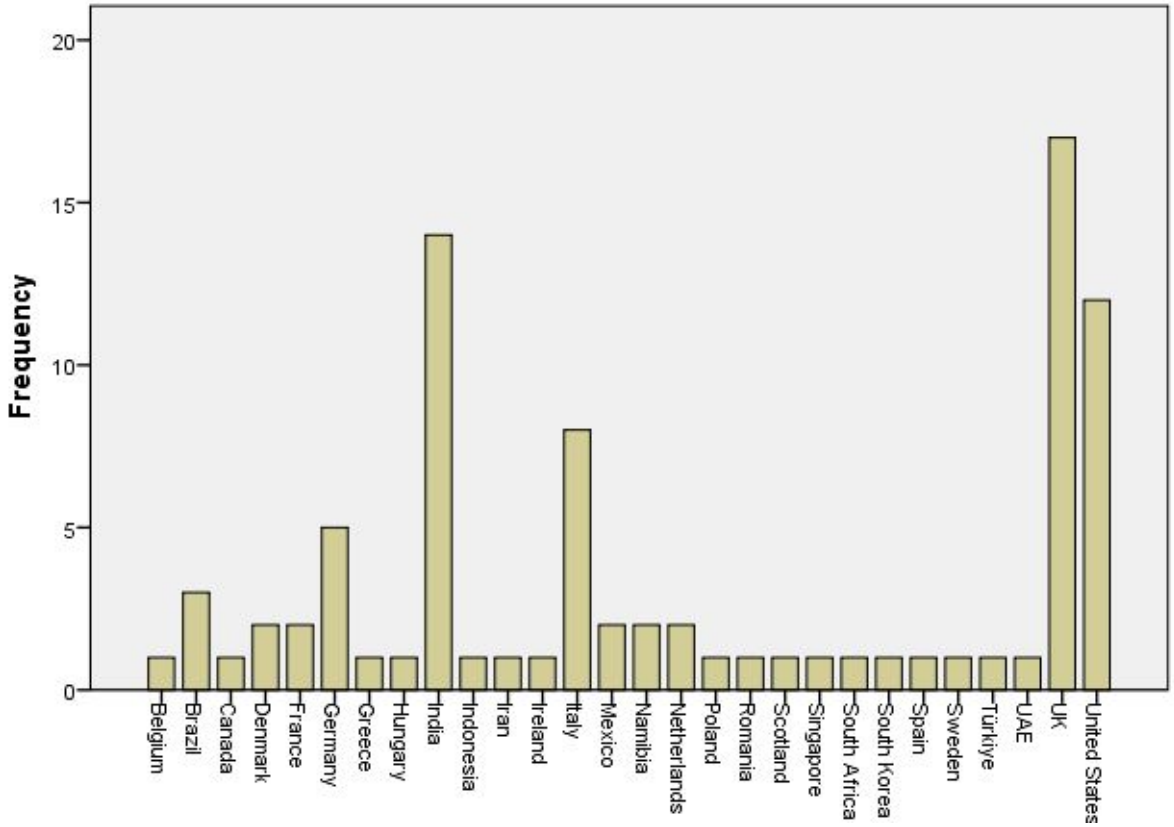

Figure 1: Country-wise distribution of respondents

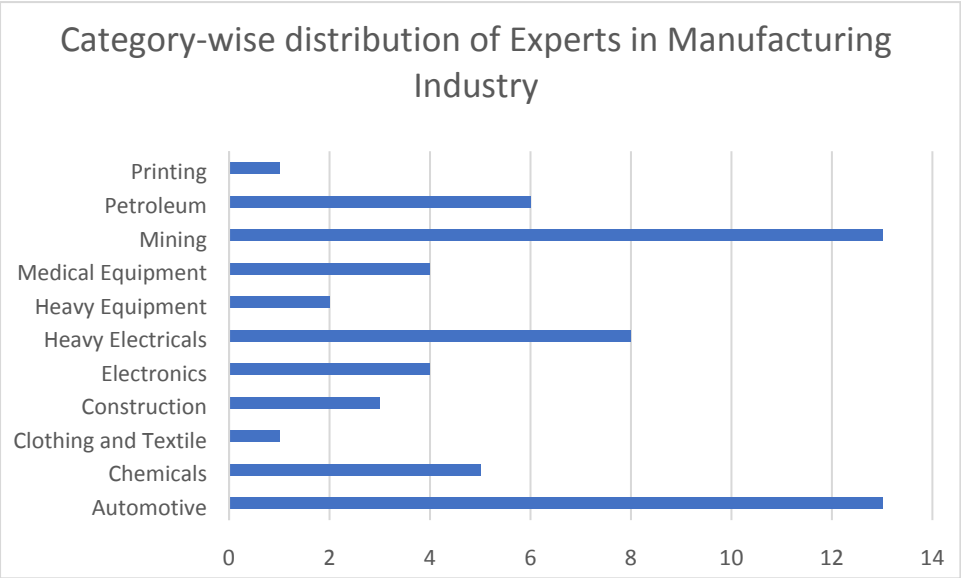

Figure 2: Company-wise distribution of Six Sigma experts in manufacturing sector

4.0 Key Findings

The first part of the top five limitations of Six Sigma from the experts in Manufacturing and academics are presented in Table 2 and Table 3. In order to test for the difference in perception of Six Sigma experts, an independent sample Mann-Whitney U test (Mann and Whitney, 1947) was conducted. As the data is of ordinal nature, a non-parametric test was conducted (Abdul Halim Lim et al., 2017).

Table 2: Top five limitations/emerging trends/research gaps of Six Sigma from experts in manufacturing

	N	Sum	Mean
Integration of Six Sigma with Big Data can bring superior results to many organizations in the future	61	378	6.20
Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises	61	374	6.13
Over emphasis on Variance reduction	61	362	5.93
Poor implementation of Six Sigma can have a negative impact on employee satisfaction.	61	355	5.82
Integration of Six Sigma and Industry 4.0 is not fully explored yet and it will be one of the next big emerging topics	61	346	5.67
Green and Six Sigma are complementary to each other and their integration would be beneficial to many companies	61	341	5.59

Six Sigma, if not implemented properly, may have a negative impact on customer satisfaction	61	329	5.39
The initial cost of implementing Six Sigma in an organization is very high	61	273	4.48
The failure rate of Six Sigma initiatives like any other organizational change initiatives is very high	61	263	4.31
The technical limitations of Six Sigma like 1.5σ shift needs to be addressed in layman terms and should not be over emphasised	61	254	4.16
Non-Standardization of training Curriculum for various Six Sigma Belts	60	242	4.03
Six Sigma is TQM on steroids	61	182	2.98
Six Sigma as a structured and disciplined approach to problem solving may stifle the employee creativity and innovation	61	175	2.87
The benefits due to Six Sigma implementation for companies are minimal with respect to the efforts	61	107	1.75
Six Sigma and its applicability for public sector organizations	61	104	1.70

Table 3: Top five limitations of experts from academics

	N	Sum	Mean
Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises	25	158	6.32
Overemphasis on Variance reduction	25	155	6.20
Integration of Six Sigma with Big Data can bring superior results to many organizations in the future	25	154	6.16
Integration of Six Sigma and Industry 4.0 is not fully explored yet and it will be one of the next big emerging topics	25	150	6.00
Poor implementation of Six Sigma can have a negative impact on employee satisfaction.	25	146	5.84
Green and Six Sigma are complementary to each other and their integration would be beneficial to many companies	25	139	5.56
Six Sigma, if not implemented properly, may have a negative impact on customer satisfaction	25	130	5.20
Non-Standardization of Curriculum	23	114	4.96
The failure rate of Six Sigma initiatives like any other organizational change initiatives is very high	25	112	4.48
The technical limitations of Six Sigma like 1.5σ shift needs to be addressed in layman terms and should not be over emphasised	25	107	4.28
The initial cost of implementing Six Sigma in an organization is very high	25	101	4.04
Six Sigma is TQM on steroids	24	82	3.42
Six Sigma as a structured and disciplined approach to problem solving may stifle the employee creativity and innovation	25	65	2.60
Six Sigma and its applicability for public sector organizations	25	56	2.24
The benefits due to Six Sigma implementation for companies are minimal with respect to the efforts	25	53	2.12

In order to understand if there are any perceived differences in the mean scores on limitations/emerging trends between the two sample means, a two sample Mann-Whitney U test was performed (Navarro, 2014). The Mann-Whitney U test is the most appropriate test in this case because the two samples are independent and categorical. The observations are independent in the sense that the participants in each sample groups are different (Montgomery et al. 2011). The summary of key findings from both clusters (experts from manufacturing companies and leading academics/research scholars) is provided in Table 4.

Table 4: Summary of key findings from both clusters (experts from manufacturing companies and leading academics/research scholars)

Limitations/Emerging Trends/Research Gaps	Mean Scores of Experts from Academics	Mean scores of Experts from Industry	Mann-Whitney U test (Asymp. Sig.)
The failure rate of Six Sigma initiatives like any other organizational change initiatives is very high	4.48	4.31	0.6760
The initial cost of implementing Six Sigma in an organization is very high	4.04	4.48	0.3480
Six Sigma, if not implemented properly, may have a negative impact on customer satisfaction	5.20	5.39	0.3250
Poor implementation of Six Sigma can have a negative impact on employee satisfaction.	5.84	5.82	0.9260
Six Sigma as a structured and disciplined approach to problem solving may stifle the employee creativity and innovation	2.60	2.87	0.5790
The benefits due to Six Sigma implementation for companies are minimal with respect to the efforts	2.12	1.75	0.041**
The technical limitations of Six Sigma like 1.5σ shift needs to be addressed to instil confidence in Organizations to implement Six Sigma	4.28	4.16	0.6630
Variance reduction should not be the only goal of Six Sigma implementation	6.20	5.93	0.8900
Six Sigma is TQM on steroids	3.56	2.98	0.2430
Non-Standardization of Curriculum	4.76	4.03	0.023**
Integration of Six Sigma with Big Data can bring superior results to many organizations in the future	6.16	6.2	0.5770
Green and Six Sigma are complementary to each other and their integration would be beneficial to many companies	5.56	5.59	0.7550
Integration of Six Sigma and Industry 4.0 is not fully explored yet and it will be one of the next big emerging topics	6.00	5.67	0.2760
Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly	6.32	6.13	0.8560
Six Sigma is not suitable for public sector organizations	2.24	1.7	0.1800

Note: ** 5% significant level

The difference in the perceptions between academics and experts from industry was significant for two limitations (P<0.05). The first difference was on *the benefits due to Six Sigma implementation for companies are minimal with respect to the efforts* and the second difference was on *the Non-standardization of curriculum*. The top five limitations/emerging trends from both clusters were notably similar, despite the order of importance or ranking. It was also observed that the average scores for most items were recorded higher for academics compared to experts from industry.

The next phase of the analysis was to understand the limitations/emerging trends across the three continents; Asia, Europe and North America. We have omitted Africa as we received only 3 responses from this continent. We did not have any participants from Australia and New Zealand in this study, but these should be included in future investigations. Table 5 presents the mean scores of each limitation/emerging trend across the three continents. The authors utilised a Kruskal Wallis H Test as the assumptions for Analysis of Variance (ANOVA) was not met for our dataset. In this case, the scores from each continent (i.e., three levels) are to be tested instead of two, and the observations recorded are independent (McKight and Najab, 2010).

Table 5: Summary of key findings from continent wise clusters (experts from manufacturing companies and leading academics/research scholars)

Limitations/Emerging Trends/Research Gaps	**Scores from experts and academics**			
	North America	**Asia**	**Europe**	**Kruskal Wallis Test (Asymp. Sig.)**
The failure rate of Six Sigma initiatives like any other organizational change initiatives is very high	3.94	5.32	4.15	0.019**
The initial cost of implementing Six Sigma in an organization is very high	4.61	4.63	4.09	0.390
Six Sigma, if not implemented properly, may have a negative impact on customer satisfaction	5.67	5.42	5.13	0.846
Poor implementation of Six Sigma can have a negative impact on employee satisfaction.	6.17	5.16	6.02	0.025**
Six Sigma as a structured and disciplined approach to problem solving may stifle the employee creativity and innovation	3.72	3.05	2.30	0.032**
The benefits due to Six Sigma implementation for companies are minimal with respect to the efforts	1.67	2.32	1.65	0.005***
The technical limitations of Six Sigma like 1.5σ shift needs to be addressed to instill confidence in Organizations to implement Six Sigma	3.72	4.68	4.17	0.195

Variance reduction should not be the only goal of Six Sigma implementation	6.00	6.26	5.98	0.919
Six Sigma is TQM on steroids	3.28	3.68	2.83	0.174
Non-Standardization of Curriculum	4.17	5.00	3.89	0.011**
Integration of Six Sigma with Big Data can bring superior results to many organizations in the future	6.28	6.05	6.22	0.352
Green and Six Sigma are complementary to each other and their integration would be beneficial to many companies	5.50	5.53	5.63	0.945
Integration of Six Sigma and Industry 4.0 is not fully explored yet and it will be one of the next big emerging topics	5.50	6.16	5.76	0.254
Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly	6.39	6.32	6.07	0.417
Six Sigma is not suitable for public sector organizations	1.39	2.68	1.54	0.001***

Note: ** 5% significant level, *** 1% significant level

Significant differences were noted in the six limitations/emerging trends across the three continents. The failure rate of Six Sigma initiatives was found to be highest in Asia compared to America and Europe. In Asia, poor implementation of Six Sigma has the lowest impact on employee satisfaction compared to America and Europe. The participants from Europe scored the least against the limitation that Six Sigma methodology for problem-solving stifles innovation. There was a significant difference in means on non-standardization of Six Sigma curriculum among the continents. This has been a serious limitation for many years and clearly needs more work to develop a standard curriculum across the sectors including manufacturing, service, public sector and even the voluntary sector. All participants were in favour of the use of Six Sigma for public sector organisations, and this explicitly shows its importance in the last few years for reducing or minimizing defects in processes as a result of excessive variation.

5.0 Discussion, Limitation & Implications

A primary emerging trend of Six Sigma is its integration with Industry 4.0 and Big Data. Experts in manufacturing companies and leading academics/research scholars felt this is a research gap which needs more attention. Only a handful of publications in the current literature mention the above gap (Schumacher et al., 2016; Bassi, 2017; Sony, 2018), with almost no work towards the creation of guidelines for integrating Industry 4.0 and Big Data with Six Sigma (Foidl and Felderer, 2015). Although Six Sigma has yielded superior results for many large manufacturing companies, its implementation in SMEs is not widely reported

due to various challenges, such as budget constraints, lack of relevant expertise, time constraints, lack of awareness and the common misconception that Six Sigma is aimed at large manufacturing corporations (Antony et al., 2005; Ben Romdhane et al., 2017).

In addition, variance reduction should not be the sole objective of a manufacturing organization, as other aspects such as organisational growth are equally important. Organization growth strategies are dependent on various factors such as innovation strategy, product expansion, market penetration, diversification etc. (Mishina et al., 2004; Adner, 2006). Poor implementation of Six Sigma will result in excessive procedural work for employees and may result in poor morale and low engagement across the business (Klefsjö et al., 2001; McAdam and Lafferty, 2004; Nakhai and Neves, 2009).

Notably, the top five limitations/emerging trends from experts in manufacturing and academics were quite similar aside from some minor differences in their rankings. For instance, the experts in manufacturing who were implementing Six Sigma felt more strongly than the academics/research scholars that the benefits of Six Sigma outweigh the efforts of implementation. This chimes with a plethora of studies supporting Six Sigma as a beneficial business strategy when implemented with passion and uncompromising commitment (Antony and Banuelas, 2002; Antony, 2004b; Antony et al., 2005; Kwak and Anbari, 2006; Sony and Naik, 2011).

A difference in perceptions was also noted around the non-standardisation of curriculum related to Six Sigma training, with academics/research scholars more concerned about the non-standardisation issues of curriculum than the Master Black Belts and Black Belts respondents. Non-Standardisation of Six Sigma education has been a significant problem over the past few decades (Laureani and Antony, 2011). Although an international standard (ISO 13053 Part 1 and Part 2) was developed to address some of the issues within Six Sigma, it has not gained widespread acceptance amongst the global Six Sigma community (Chiarini, 2013).

Some studies find Six Sigma influenced by national culture (Schön et al., 2010). The rapid growth of Six Sigma in US corporations compared to those in Europe is due to a better cultural fit , whereby US corporations are typically decentralised and formal (Crom, 2000; Klefsjö et al., 2008). Our study finds that experts from Asia felt that the failure rate of Six Sigma initiatives is comparatively higher in Asia than that in Europe and USA. One of the potential reasons for this is that many organisations in Asia implement Six Sigma without

looking into the cultural and leadership aspects related to the implementation (Krishna et al., 2008). Poor implementation of any initiative would result in poor employee morale and employee dissatisfaction. Our analysis shows that there is a significant difference in the mean scores across the three continents for poor implementation of Six Sigma and its impact on employee satisfaction.

The Six Sigma experts in America and Europe differed on the extent to which Six Sigma as a structured and disciplined approach to problem solving might stifle employee creativity and innovation. As culture can impact creativity (Chua et al., 2015), so a structured approach could be considered a source of creativity in one culture and not so in another.

The findings of the study have a number of practical implications. First, understanding the major limitations of one of the most powerful business process improvement methodologies creates a foundation for both industrial experts and leading academic scholars upon which to discuss and develop strategies to address and overcome these limitations. For instance, the use of Six Sigma in SMEs is not very common due to various misconceptions around the topic, and a lack of understanding and awareness of the benefits of Six Sigma in the SME context. One of the major gaps concerns the development of a generic, practical, user-friendly and easy to use roadmap charting the passage from cultural readiness to implementation and deployment to sustainability of Six Sigma. This would encourage a number of SMEs to implement Six Sigma towards creating and sustaining competitive advantage. Second, there is a need for the development of a standard curriculum customised for SMEs including contents, number of training days, the scope of Six Sigma projects in the context of SMEs, the infrastructure required for implementation and sustainability of Six Sigma in SMEs, and finally the customised toolkit for process improvement activities in SMEs. Aside from limitations, the emerging trends of Six Sigma are equally important, and senior managers in organisations should pay attention to these emerging trends in order to maximise organisational growth and sustain competitiveness.

As with any research, this study has some limitations. First, the sample size of the survey was low for making statistically valid conclusions from the data. One of the major challenges in the study is to increase the sample size of academics, as only a handful of academics and research scholars have published peer reviewed papers in top tier international journals. Our samples have no representation from the Australian continent and it would be interesting to see how the findings vary between Europe, North America and Australia. Moreover, we had

limited samples from the African continent. This is because only a small number of corporations in Africa are implementing Six Sigma. The authors have not included SMEs in the study and it would be interesting to see how the findings vary between large and small and medium sized manufacturing enterprises.

6.0 Conclusion & Future Research Agenda

To the best of authors' knowledge, this is the first empirical study addressing the limitations and emerging trends/research gaps of Six Sigma. The top five limitations/emerging trends/research gaps according to the Six Sigma experts from large manufacturing companies and academics were:

- *integration of Six Sigma with Big Data;*
- *use of Six Sigma in Small Medium and Micro enterprises;*
- *overemphasis of Six Sigma on variability reduction;*
- *poor implementation of Six Sigma and its negative impact on employee satisfaction;*
- *non-exploitation of integration of Six Sigma with Industry 4.0.*

It was interesting to observe some perceived differences in the mean scores between the industry experts and academics on two items: the balance of benefit to effort of Six Sigma implementation, and the non-standardization of the Six Sigma curriculum. There were also significant differences in the mean scores for a number of limitations/emerging trends across the three continents participating in our investigation; Asia, Europe and North America. Future research can be directed at collecting more samples from the manufacturing and academics. The authors intend to include a number of SMEs in the next study so that a comparative study on the limitations between large and SMEs (manufacturing) can be carried out. Finally, the authors plan to include service and public sector organisations in future research, which would enable the authors to critically evaluate the limitations and emerging trends of Six Sigma across various industrial sectors.

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